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TROPICAL PLUMES IN A BAROTROPIC MODEL

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1. INTRODUCTION

The tropical central and eastern Pacific atmosphere is dominated by extensive regions of subsidence and upper-tropospheric westerly winds during Northern Hemisphere (NH) winter; these features are typically associated with the Walker circulation. Satellite water vapor imagery commonly depicts large extremely dry oval-shaped regions. They are dominated by intense tropospheric subsidence extending deep into the tropics, occasionally across the equator. They are transient, exhibiting individual lifetimes from days to a few weeks. Also observed is a common synoptic-scale system known as a tropical plume (McGuirk et al. 1988). Given the high frequency of tropical plumes developing immediately downstream of the dry regions, it is hypothesized that plume formation and maintenance depend on locally intense upper tropospheric convergence and subsidence to the west. This subsidence may be associated with fluctuations of the Walker circulation.

This study uses a divergent barotropic shallow-water model to investigate the relationship between locally intense upper tropospheric convergence and subsequent downstream tropical plume development. Although baroclinic and convective processes may play a role in plume development, dominant mechanisms appear to be barotropic. Only barotropic dynamics are examined, even though these dynamics may not provide a complete explanation of plume behavior. The source of convergent forcing is not examined. The objective of this research is to reproduce and evaluate the upper-tropospheric flow features of tropical plumes in a barotropic model with a realistic basic state forced by convergence; the realistic basic state consists of five-year mean January 200 mb divergent and nondivergent winds.

2. MODEL

The shallow water model contains a single barotropic layer of fluid, homogeneous and incompressible. The model utilizes a square-grid "channel" geometry, true at the equator; grid spacing for like variables is 2° lat/lon. A geometrically correct Coriolis force is used. The model uses potential enstrophy conserving finite differencing on a staggered C-grid. The time step is 9 min and the average fluid depth is 900 m. Solid free-slip boundaries exist along 80°N and 80°S, east-west boundaries are periodic, and Laplacian lateral friction is imposed as well as a "sponge" filter poleward of 50o latitude. Mid-latitude dynamics are poorly simulated. Basic state and transient divergent forcing are imposed, and mass is conserved with a compensating adjustment spread evenly over all model grid points.

Numerous experiments are conducted. A 15 d control run tests basic state stability. Simulations test the sensitivity of this basic state to isolated synoptic-scale transient convergent forcing (over an oval 15-20° in radius), to simulated surges in the Walker circulation, and to premature elimination of nearby transient convergent forcing.

3. RESULTS

Development of tropical plumes within the basic state is highly sensitive to the location and duration of transient convergent forcing. Seven simulations fail to produce tropical plumes. Five tropical plumes are simulated, four in response to a single center of transient convergent forcings located between 141°W and 167°W, and 5°N and 11°N. A surge in the Walker circulation produces an exceptionally strong and persistent plume. When the transient convergent forcing is prematurely terminated, a well-developed tropical plume rapidly dissipates immediately thereafter.

Typical plume behavior is examined by compositing the five plumes at their maximum intensity. The composited geopotential field (Fig 1a) exhibits a positively tilted trough over the east Pacific, from the equator near 151°W to the North American coast. The composited stream function trough (Fig. 1b) intersects the equator 20° farther east near 130°W. Significant cross-contour (down-gradient) flow are found near these tropical troughs.

The simulated tropical plumes satisfy 3 criteria of an objective definition:

1. A subtropical trough (Fig. 1) with a height difference greater than 180 m along 20°N within 30° of the trough axis, and positioned near the western edge of the plume (Fig. 2).
2. An anticyclonically-curving subtropical jet greater than 45 ms^{-1} (Fig. 2) emanating from the plume source region east of the trough axis, with meridional speed shear exceeding 25 m s^{-1} between the equator and 20°N.
3. A convergence/divergence dipole (Fig. 3) (exceeding $1x10^{-5}$ s^{-1}) equatorward of 15°N latitude persisting for at least 12 h (Fig. 3), straddling the trough axis (Fig. 1), and associated with the subtropical jet entrance region (Fig 2).

If any of these features are absent, the simulated flow is not a tropical plume.

Simulated tropical plumes generate Rossby wave trains (Fig. 4) which propagate eastward and initiate plume-like systems downstream over the Atlantic Ocean, North Africa and southern Asia. Plumes exhibiting the greatest longevity and intensity generate the longest-lived and most intense Rossby wave trains. The Rossby wave source is

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within the plume source region where advection of absolute vorticity by the divergent wind is strong.

4. DISCUSSION

The simulated tropical plumes in this study display remarkable similarity to many observed plume characteristics. As the simulations evolve, the basic state divergence and transient forcing gradually modulate the non-divergent basic state, allowing a continuum of near climatological states to be sampled. A region of negative absolute vorticity develops north of the equator and east of the dateline. When plumes develop, the convergent forcing occurs along the zero vorticity isopleth. The implication is that inertial instability is an important mechanism. Not all forcings along the zero isopleth lead to tropical plumes, implying sensitivity to the details of the basic state.

5. REFERENCES

McGuirk, J.P., A.H. Thompson and J.R. Schaefer, 1988: An eastern Pacific tropical plume. *Mon. Wea. Rev.*, 116, 2505-2521.

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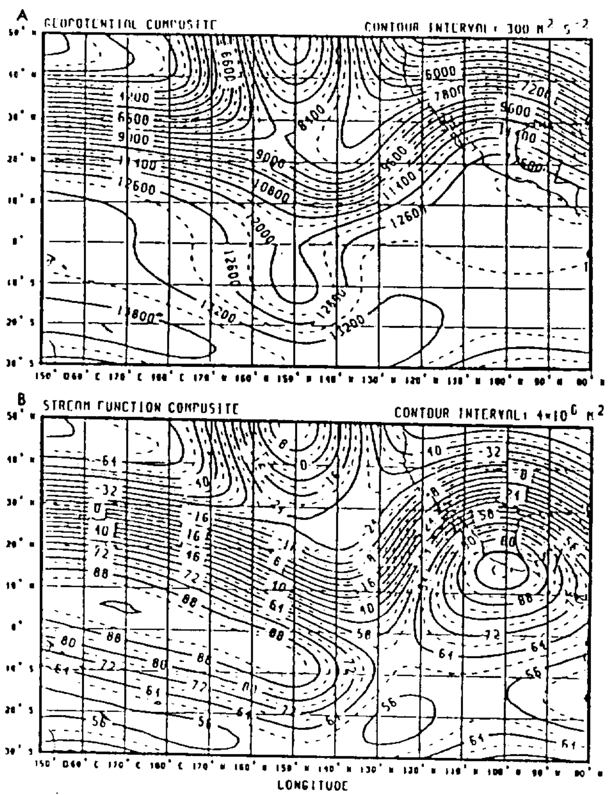

Fig. 1. Composite of (a) geopotential and (b) stream function for 5 simulated tropical plumes at maximum intensity. All plumes are shifted to a common reference location before compositing.

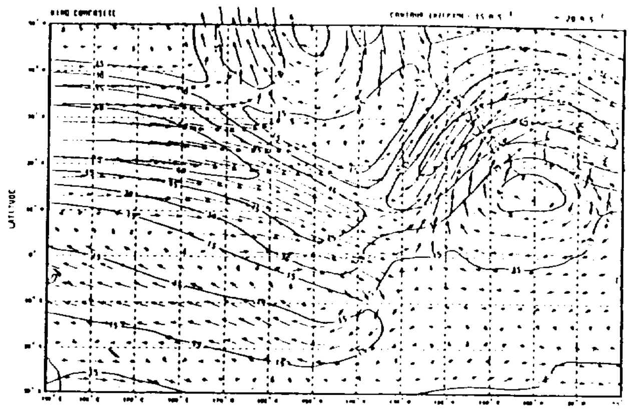

Fig. 2. Composite wind vectors and isotachs for 5 simulated tropical plumes at maximum intensity.

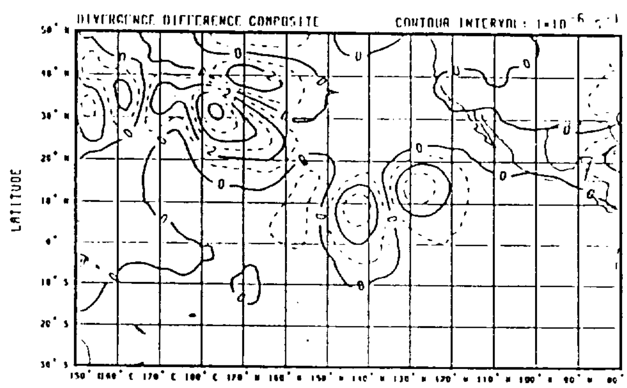

Fig. 3. Response divergence (total minus transient and basic state divergence) composite for 5 simulated tropical plumes at maximum intensity.

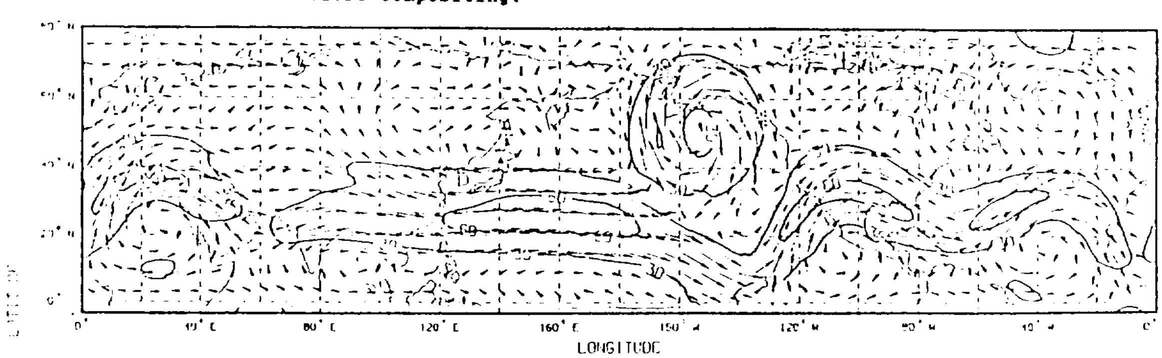

Fig. 4. East Pacific wind vectors and isotachs displaying a Rossby wave train emanating from a simulated east Pacific tropical plume. Plume-like systems are observed within this wave train over the western Atlantic and western Africa.